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# Environmental Health-Risk Assessment for Tritium Releases at the National Tritium Labeling Facility at Lawrence Berkeley National Laboratory

**by**

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# Contents

# Chapter 1

# Introduction and Summary of Results

In talking with community members about operations at Lawrence Berkeley National Laboratory (LBNL) (the Laboratory), we found that people are concerned about a radioactive substance, tritium, used at the Laboratory. State, federal and international agencies all have standards for limiting human exposure to tritium in both occupational and non-occupational populations. LBNL has always maintained exposure to tritium well below the regulatory levels (see Table 1-3 for a comparison). Nevertheless, LBNL continues to evaluate and implement new methods to further reduce the emission of tritium to the environment.

In response to the community's concern about the **risk**[1] of being exposed to tritium released from LBNL, the Laboratory conducted a formal analysis, known as a "**risk assessment**," of potential health impact from tritium **exposure.** This first chapter presents a brief non-technical summary of the results of the risk assessment, and Chapter 2 contains basic information about tritium, radiation, and the National Tritium Labeling Facility (NTLF). The other chapters provide detailed information and equations showing how the risk assessment was done. If you have questions about the information presented here, you may call Ronald Kolb in LBNL's Public Communications Department at 510-486-7586.

LBNL also prepared a fact sheet, "Questions and Answers about Tritium," which was distributed in the winter of 1992-1993. The fact sheet is included as Appendix I of this document, and some of the text is repeated below. You may request additional copies of the fact sheet by telephoning Ronald Kolb.

In this report we use both SI and US units. Readers can use the table in Appendix G to make conversions.

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[1] Words in boldface type are defined in the Glossary at the end of this book.

## 1.1 Summary of risk assessment results

This risk assessment calculates the probability of experiencing health effects, including cancer incidence due to tritium exposure for three groups of people: (1) LBNL workers near the LBNL facility—Building 75—that uses tritium; (2) other workers at LBNL and nearby neighbors; and (3) people who use the UC Berkeley campus area, and some Berkeley residents. All of these groups share the same probability of health effects from the background **radiation** from natural sources in the Berkeley area environment, including an increased risk of developing a cancer of 11,000 chances per million. In calculating risk we assumed continuous operation in Building 75 for at least a human lifetime. Under this assumption, LBNL workers located near Building 75 have an additional risk of 60 chances out of one million to suffer a cancer; other workers at LBNL and people who live near LBNL have an additional risk of six chances out of one million over a lifetime of exposure; and users of the UC Berkeley campus area and other residents of Berkeley have an additional risk of less than one chance out of one million over a lifetime. These risk estimates are discussed further in Sections 1.13 through 1.17.

## 1.2 Organization of this chapter

The sections that follow in this chapter look at:

- Facts about tritium: what it is, how it is used at LBNL, and its radiological characteristics
- Steps in a risk assessment
- How workers and community members might be exposed to LBNL tritium
- Potential health effects of tritium exposure
- The probable risk from tritium exposure
- Uncertainty in the risk assessment
- Validity of the input tritium concentrations for risk assessment
- Subsequent chapters of the report
- Responses to reviewers' comments on the draft version of this document

## 1.3 What is tritium?

Tritium is a radioactive form of hydrogen. Since tritium behaves like hydrogen chemically, it is usually found attached to molecules in place of hydrogen. For example, a water molecule may exchange one of its hydrogen atoms for a tritium atom, resulting

in "tritiated water." Tritiated water is sometimes referred to as "HTO" to distinguish it from $H_2O$, ordinary water with two ordinary hydrogen atoms in each molecule.

Tritium is produced both by a natural process, the interaction of cosmic rays with the atmosphere, and by man-made processes (in nuclear reactions). About 80 percent to 90 percent of tritium in the environment today was released in the 1950s and early 1960s by above-ground nuclear weapons testing in many countries. Tritium is also used in a variety of consumer products, such as illuminated watches, thermostat dials, and airplane exit lights. Both the natural and man-made sources have contributed (and continue to contribute) to a world-wide "background" level of tritium.

The half-life of tritium is 12.3 years. This means that the concentration of tritium in the environment is reduced by one-half every 12 years, disregarding newly generated tritium.

## 1.4 Why is tritium used at Lawrence Berkeley National Laboratory?

At LBNL, the NTLF (Building 75 in Figure 1-1) uses tritium. The NTLF helps biomedical researchers develop new ways to study cell metabolism and test new products that can be useful in curing diseases. Researchers "label" pharmaceuticals and other materials with tritium by replacing a hydrogen atom with a tritium atom in materials used in experiments. For example, a potential cancer drug might be labeled so that researchers can study the transport of the tritium-labeled drug in a cell culture and evaluate its effectiveness in treating a particular type of cancer.

## 1.5 What are tritium's radiological characteristics?

When tritium undergoes radioactive decay, it is transformed into nonradioactive helium through the emission of a **"beta" particle**, or electron, from its nucleus (see Figure 1-2). The very low energy radiation emitted by tritium is too weak to present a radiation hazard outside of the human body. The radiation from tritium can only travel about 5 millimeters in air and can be stopped completely by a sheet of paper or by ordinary clothing.

Tritium *can* deliver a radiation **dose**, however, if it is taken *inside* the body. Such an intake could occur by breathing tritiated water vapor in the air, or by eating or drinking tritium-contaminated foods or water. Even though tritium radiation cannot penetrate skin, tritiated water vapor in air, like regular water vapor in air, may be absorbed through the skin. Likewise, a person might absorb small amounts of tritiated water through the skin when swimming or wading in contaminated water. A developing fetus could also receive tritium absorbed into its mother's body through one of these routes.

Most tritium taken into the body is rapidly distributed throughout the body as tritiated water, HTO. Since these HTO molecules behave just like normal water molecules, they are subject to the normal rate of removal of water from the body. Thus, the amount of tritium entering the body is reduced by half about every two weeks. A small portion of tritium in the body may be "organically bound tritium," tritium that has been incorporated into molecules that make up plant or body cells. Organically bound tritium is metabolized differently than HTO and can be retained for somewhat longer periods, with the amount being reduced by half about every seven weeks.

## 1.6 What steps are necessary to assess tritium risk?

For the purpose of estimating risk from tritium emissions, risk assessment involves four interrelated steps: 1) determining the amount of tritium released and how it is released; 2) based on step 1, determining the levels of tritium to which people could be exposed and the routes through which they could be exposed; 3) determining the potential health effects of exposure to these levels of tritium; and 4) arriving at an estimate for the probability of experiencing a health effect, given the foregoing information.

## 1.7 Does the tritium at LBNL escape into the environment?

Small quantities of tritium are emitted from the ventilation stack at Building 75 to the environment in forms of molecular tritium ($T_2$ or HT) and tritiated water (HTO). HTO is taken up by organisms and environmental media far more readily than molecular tritium. Therefore, to make the risk assessment health protective, we assume that all tritium emissions are in the form of HTO. The dose that a member of the public could receive from the contribution of these emissions to the air is approximately 100 times lower than the limit permitted by federal regulations. LBNL takes samples from stack emissions, air, local rainfall, ground water, streams, and sewers to check for tritium. The Laboratory publishes these monitoring results annually in environmental reports that are provided to all regulatory agencies and are available at public libraries.

LBNL has detected tritium in soil, rainwater, and ground water in the immediate area of Building 75. Occasionally, the levels detected in rainwater and ground water at some locations around Building 75 have been slightly above the drinking water standard established by the U.S. Environmental Protection Agency (EPA). However, none of this water is used for drinking, and none flows into any sources of drinking water for Berkeley. The tritium levels are very low in other drainage channels on site. The creeks flowing out of the Laboratory area also are monitored for tritium. Tritium has been detected occasionally in Strawberry and Blackberry Creeks, but at levels that are much less than the EPA drinking water standard.

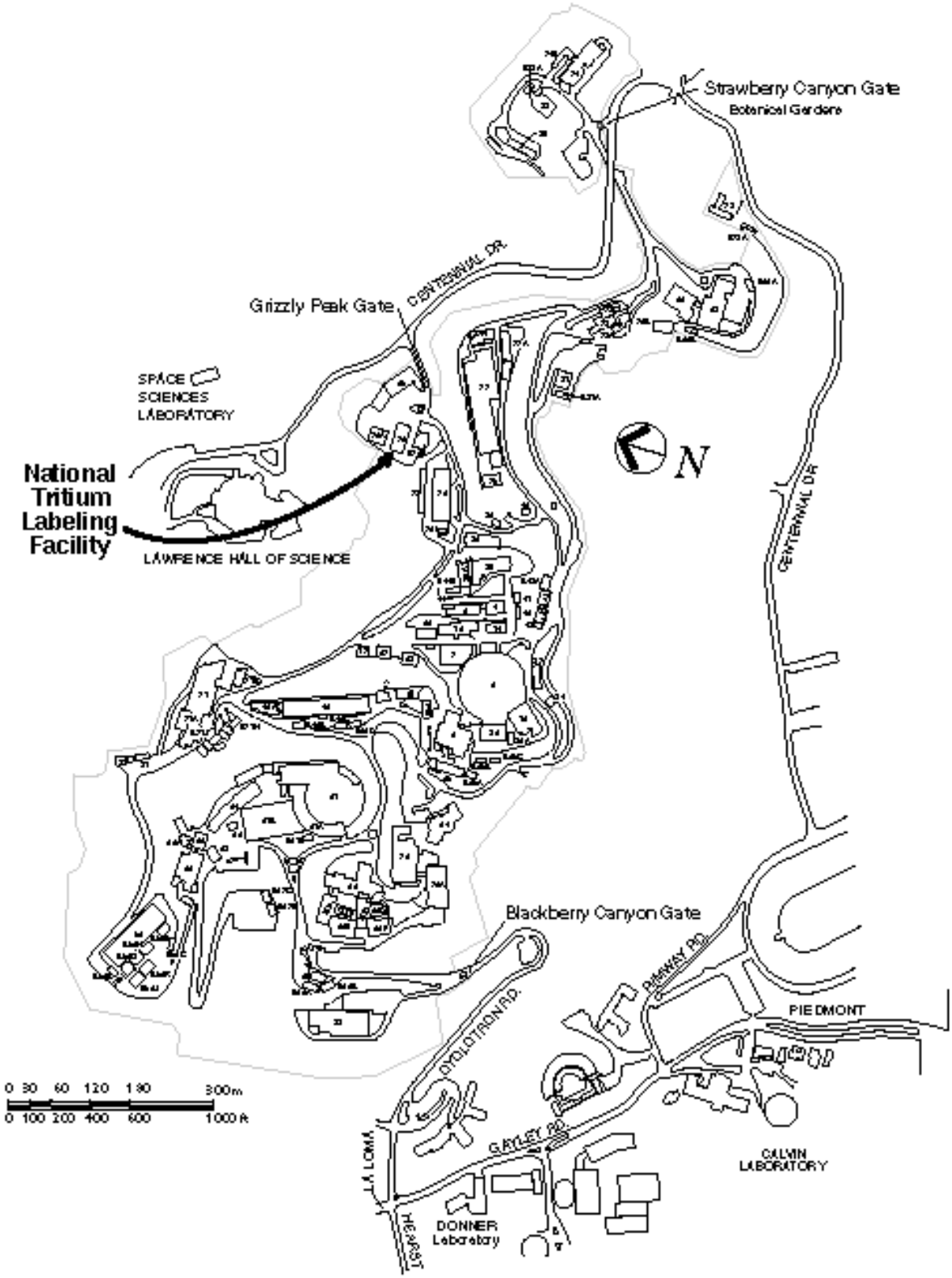
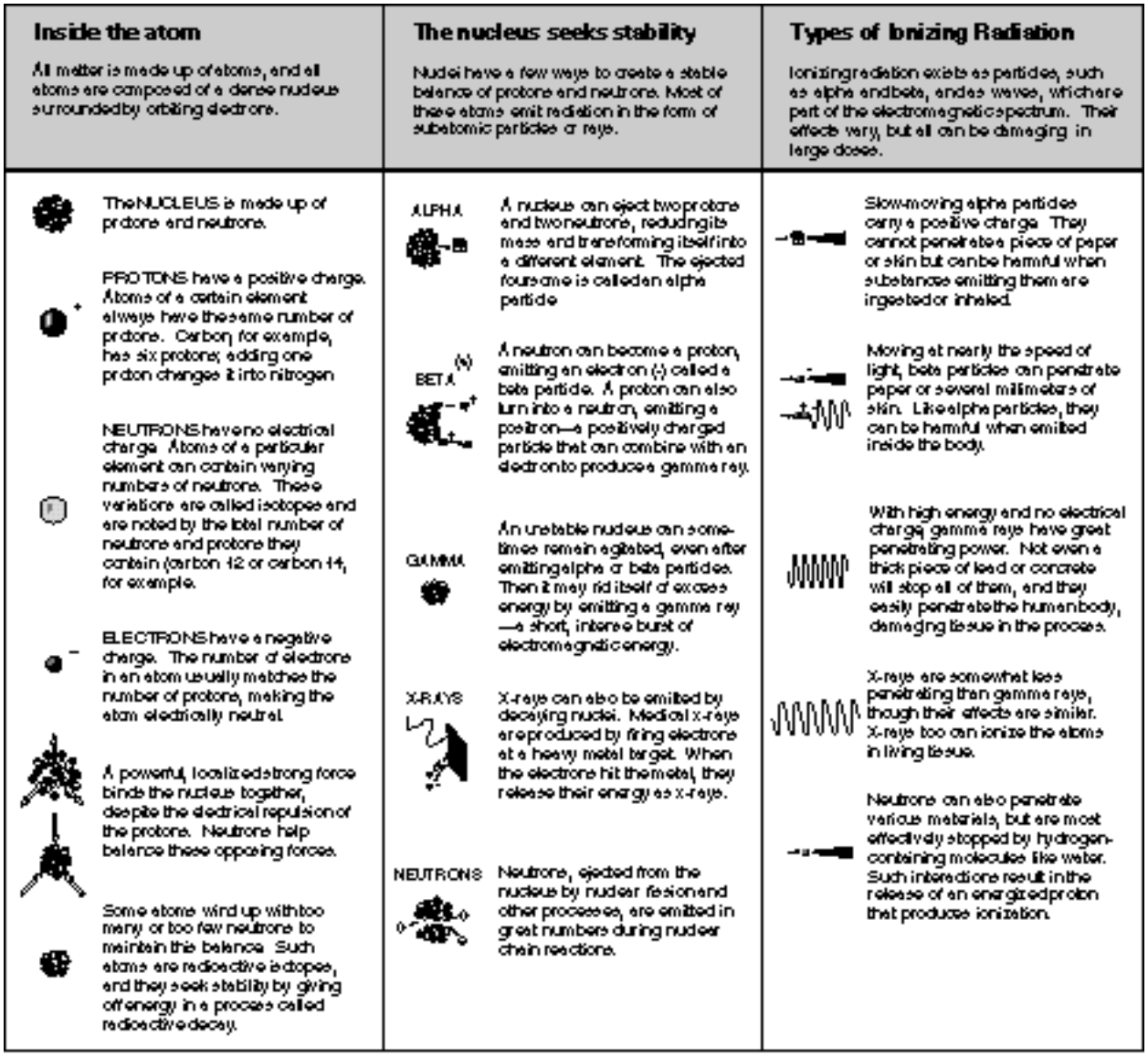



**Figure 1-1.** Location map. The NTLF is located in Building 75 on the LBNL site.




**Note to Figure 1-2:**

**(a)** While some beta particles can penetrate human skin, tritium's beta particles do not have enough energy to do so. Their maximum depth of penetration is .006 millimeters, compared to the thickness of human skin ranging from one to three millimeters.

**Figure 1-2.** Types of **ionizing radiation** (from *Health Risks Associated with Low Doses of Radiation*, report prepared by S. Cohen and Associates and ICF Kaiser Engineers for the Electric Power Research Institute, August 1994, EPRI TR-104070, Palo Alto, CA. Used by permission of the Electric Power Research Institute).

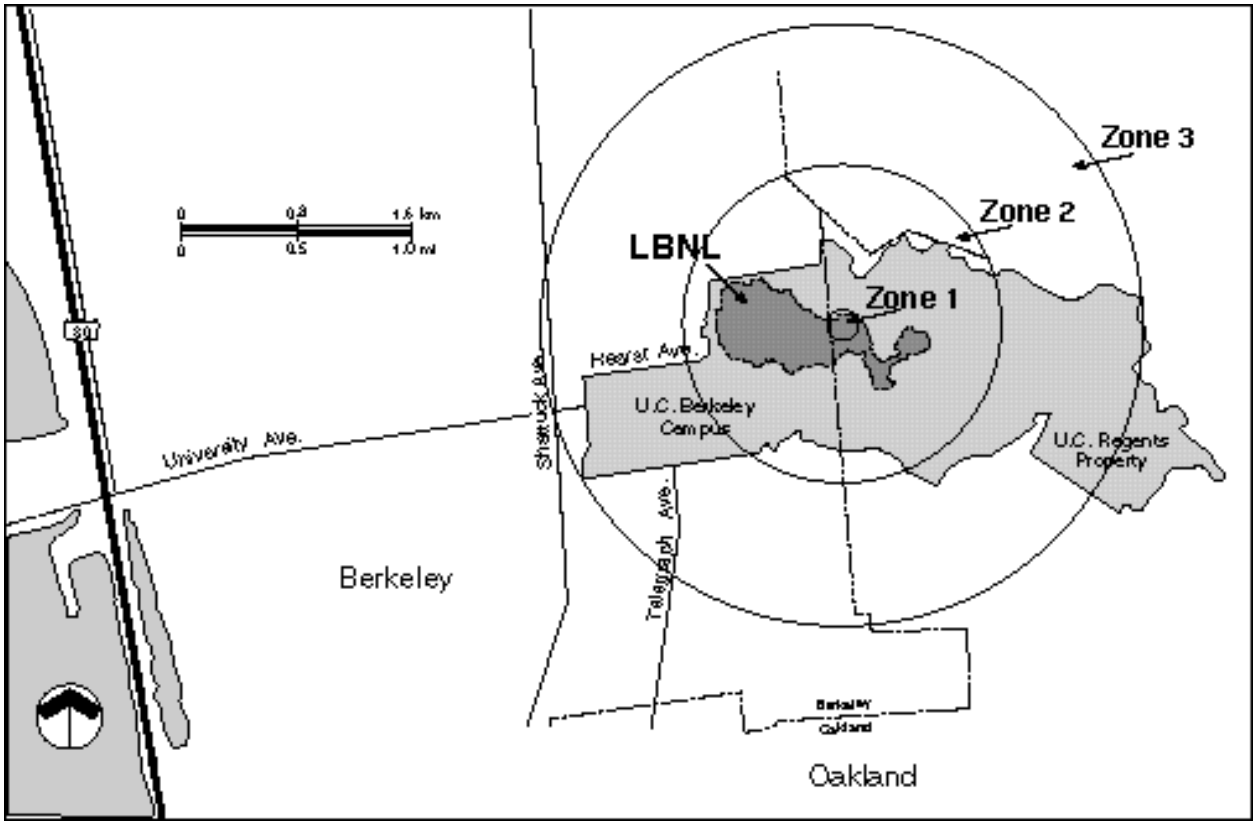



**Figure 1-3.** Map showing NTLF risk assessment zones.

## 1.8 How might someone be exposed to tritium from LBNL?

The risk assessment considered three zones in which people might be exposed to tritium from LBNL, from the zone of highest likely exposure (Zone 1) to the zone encompassing the UC Berkeley campus (Zone 3). With the center at the northeast corner of Building 75 (NTLF), the borders of the three zones are concentric circles with radii of 100, 1100, and 2100 meters, respectively (Figure 1-3).

Zone 1 includes the natural bowl that surrounds the NTLF building (Building 75) and its ventilation stack, including everything within 100 meters of the northeast corner of Building 75. People who work in this area (assuming 200 adults with 20 nursing infants) are at the most risk of exposure to tritium, by breathing tritiated water vapor and absorbing it through their skin.

Zone 2 covers the rest of entire LBNL site and the surrounding UC property occupied by the Lawrence Hall of Science, Samuel Silver Space Sciences Laboratory, Mathematical Sciences Research Institute, and Botanical Gardens. Also included are single family residences uphill from the NTLF along Grizzly Peak Boulevard. Workers and residents in this area (assuming 10,000 adults and 1,000 nursing infants) are at

lesser risk of exposure to tritium, by breathing tritiated water vapor or absorbing it through the skin or, possibly, in the case of residents, ingesting tritium that has been taken up by home-grown fruits and vegetables.

Zone 3 includes the UC Berkeley campus and adjacent areas of Berkeley beyond Zone 2. People who live, work, study, or otherwise spend time in this area (assuming 100,000 adults and 10,000 nursing infants) could be exposed to tritium dispersed by wind from the NTLF stack or washed by rain from the air near the NTLF into surface-water runoff and carried down into Strawberry Creek.

## 1.9 Is tritium hazardous to human health? What do we know?

The fact that tritium emits very low-energy radiation, is diluted throughout the body, and is eliminated fairly quickly from the body makes tritium one of the least hazardous radioactive materials. Again, tritium is a potential health risk only if it is taken inside the body.

The only studies that show radiation effects on human health are studies of individuals exposed to high dose levels (e.g., from the atomic bombings of Hiroshima and Nagasaki) -- well above those associated with background radiation, which is orders of magnitude higher than tritium from the NTLF. There are no human studies that demonstrate a link between exposure to low-level radiation and health effects. Nonetheless, it is *assumed* that low-dose radiation does affect health. The health risk estimates in this risk assessment are extrapolated from effects observed only at high dose levels.

There is evidence from experiments with animals and cell cultures that exposure to very high levels of radiation from HTO results in mutations and cell disruptions that can lead to health effects associated with radiation, including cancer. Both leukemia and non-leukemia soft-tissue carcinomas are associated with high levels of HTO exposure. Based both on the Japanese case and experimental evidence, this risk assessment assumes that the likelihood of an individual suffering a cancer as a result of exposure to tritium depends upon the magnitude of the dose of tritium radiation and the time period over which the dose is received.

Risk estimates for low doses of low linear-energy-transfer radiation, such as those for NTLF tritium releases, are based on linear extrapolation from selected populations exposed to relatively high dose rates—that is, greater than 100 millisieverts (mSv) for very short time periods (that is, seconds or minutes).[2] When dose levels are much lower and permit natural repair of radiation damage, they could result in a much smaller biological effect per unit dose. Dose levels for uncontrolled areas near the

[2] See Section 1.10 for definitions of sievert and millisievert.

NTLF are several orders of magnitude below these small doses and are estimated to be no greater than 0.005 mSv.

To date there is no direct experimental evidence that HTO or other tritium exposure causes genetic defects (genetic damage that results in observable defects that are capable of being carried on to succeeding generations) or noninheritable developmental effects in animals [Straume, 1993]. However, based on the genetic effects and noninheritable developmental effects identified in the Japanese case, it is possible that tritium exposure has this potential. As with cancers, it is assumed that the risk of birth defects from exposure to tritium is proportional to the relative magnitude of the dose and the time period over which that dose is received.

## 1.10 How much radiation are workers exposed to from the NTLF?

LBNL monitors the level of internal radiation to employees by taking and analyzing urine samples from employees working near the NTLF and elsewhere. Dose equivalent is measured in units known as **sieverts** (**Sv**) and "millisieverts" (mSv; 1000 mSv = 1 Sv). One sievert is equal to 100 rem. These units represent the energy of the absorbed radiation and how much damage the particular kind of radiation can produce. The allowable workplace dose from tritium radiation for a one-year period is 50 mSv under federal regulations. The International Commission on Radiological Protection (ICRP) has recommended a reduction in the allowable annual workplace dose to 20 mSv. The average annual dose from tritium for LBNL employees who work in the NTLF, based on measurements of tritium in urine, is calculated to be 0.55 mSv. This is about 36 times lower than the annual workplace dose recommended by the International Commission. For other LBNL workers who work in Zone 1, the average annual dose from tritium, based on the 1995 measurements of tritium in urine, is calculated to be 0.0025 mSv. For LBNL workers further away from the NTLF, the dose is less.

For comparison's sake, it has been estimated that the average dose of radiation over the course of one year for an individual living anywhere in the U.S. is approximately 3.6 mSv from all natural sources of radiation [NRC, 1990]. Radon, a natural radioactive gas produced when uranium or radium decays, produces about 2 mSv, or about 56 percent of this natural radiation. Other natural sources include radioactive products created by cosmic rays, such as carbon-14, and radioactive elements, such as uranium [NRC, 1990]. In Alameda County, the contribution of radon to the total annual background radiation dose is lower—about 1 mSv [Price and Nero, 1996]. It follows that in Alameda County the average annual background radiation dose is on the order of 2.6 mSv, or about 72 percent of the national average.

# 1.11 What are the estimated risks due to tritium exposure?

This risk assessment calculates the **probability** that a health effect will occur in a group of people exposed to NTLF tritium and the probability that a particular individual in the group will suffer a health effect. Most of these probabilities are small. One way to evaluate them is to compare the magnitude of the risk between groups. Another way is to compare the risk associated with exposure to NTLF tritium with the risk associated with exposure to background radiation from natural sources.

Table 1-1 presents the estimated risks of incurring a fatal cancer, as well as of cancer incidence, due to exposure to background radiation from all natural sources in Berkeley and the U.S. This gives a baseline against which to measure the *added* risk incurred by workers and community members exposed to LBNL tritium, which is given in Table 1-2. These results are the subject of Sections 1.13 through 1.17.

Table 1-1
Estimated Health Risks in the Berkeley Area and in the US [in Brackets] Due to Background Radiation From Natural Sources

| Health Effect | Berkeley Area Estimated Risk Levels [U.S. Estimated Risk Levels] | |
|---|---|---|
| | **Population Risk** (incidence per year per million population) | **Individual Risk** (lifetime risk, chances per million) |
| Cancer incidence(a) | 160 [220] | 11,000 [15,000] |
| Cancer mortality | 130 [180] | 9,000 [13,000] |
| Severe hereditary effects including genetic defects(b) and developmental defects(c) | 34 [47] (d) | Not calculated |

**Notes to Table 1-1:**

(a) In this study we develop risk factors for cancer mortality; to estimate cancer incidence from cancer mortality, we use the ratio 6/5, which is the incidence/mortality ratio recommended by the International Commission on Radiological Protection (ICRP) in 1991.

(b) Genetic damage that results in one or more observable defects that are capable of being carried on to succeeding generations.

(c) Effects on the formation or development of a fetus that result in one or more observed defects that are not passed on to succeeding generations.

(d) Based on a risk factor of 0.013 severe hereditary effects per Sv (ICRP, 1991).

Table 1-2
Estimated Health Risks Due to NTLF Tritium Releases

| Health Effect | Estimated Risk Levels | |
|---|---|---|
| | **Population Risk** (incidence per year in the exposed population) | **Individual Risk** (lifetime risk, chances per million) |
| **Zone 1 (assumes 220 people at risk)** | | |
| Cancer incidence[a] | 0.0004 | 60 |
| Cancer mortality | 0.0003 | 50 |
| Genetic defects[b] | 0.0000009 | 0.09 |
| Developmental effects[c] | 0.00002 | 2 |
| **Zone 2 (assumes 11,000 people at risk)** | | |
| Cancer incidence[a] | 0.001 | 6 |
| Cancer mortality | 0.0009 | 5 |
| Genetic defects[b] | 0.000003 | 0.005 |
| Developmental effects[c] | 0.00006 | 0.1 |
| **Zone 3 (assumes 110,000 people at risk)** | | |
| Cancer incidence[a] | 0.002 | 0.9 |
| Cancer mortality | 0.001 | 0.7 |
| Genetic defects[b] | 0.000004 | 0.0008 |
| Developmental effects[c] | 0.0001 | 0.02 |

**Notes to Table 1-2:**

(a) In this study we develop risk factors for cancer mortality; to estimate cancer incidence from cancer mortality, we use the ratio 6/5, which is the incidence/mortality ratio recommended by the ICRP (1991).

(b) Genetic damage that results in one or more observable defects that are capable of being carried on to succeeding generations.

(c) Effects on the formation or development of a fetus that result in one or more observed defects that are not passed on to succeeding generations.

## 1.12 What is the likelihood that a worker or community member will suffer a health effect as a result of exposure to background natural radiation?

The risk estimates in the tables are presented in two ways, as individual risk and population risk. *Individual risk* quantifies the increased likelihood that one person, in a lifetime, would suffer the particular health effect. Table 1-1 shows that every person in the U.S. has an increased risk of 15,000 chances in a million (1.5 percent) of incurring cancer in his or her lifetime due to exposure to the current concentration of background radiation from natural sources in the environment. Individuals in the Berkeley area have an increased risk of 11,000 chances in a million (1.1 percent) of incurring cancer in their lifetimes.

*Population risk* quantifies the occurrence of the health effect to be expected per year for a given population size. The population risk is based on the collective dose among a number of individuals instead of the dose to one individual. The population risk is determined by multiplying a representative annual average dose for each group of individuals at risk (infants, workers, residents, etc.) by the number people in that group and by a risk factor for a particular health outcome (cancer mortality, genetic defects, or developmental effects). In Table 1-1, the value of 160 for population risk means that for every million people exposed to background radiation in the Berkeley area, it is estimated that there will be 160 cancers each year resulting from exposure to background natural radiation.

## 1.13 What are the risks from LBNL tritium to workers near the NTLF?

Compared to a person not exposed to NTLF tritium, an *individual* worker in Zone 1 is predicted to have an increased likelihood of 60 more chances out of a million or (0.006 percent) in his or her lifetime to incur cancer as a result of exposure to NTLF tritium (see Table 1-2). This risk is less than 1 percent of the risk from background radiation of 11,000 chances in one million.

An additional risk not shown on Table 1-2 is that a child born to a woman who works in Zone 1 during pregnancy and while nursing the child has an estimated increased cancer risk of eight chances in a million over a child born to a mother who works elsewhere. This estimated risk assumes transfer of tritium from the pregnant mother to the fetus and subsequently to the child throughout two years during which the child consumes only the mother's milk. This scenario is hypothetical and has no basis of measurement data. It is used to make the risk assessment conservative and health protective.

Assuming a *population* of 200 people working in Zone 1 with an assumed 20 nursing infants, the likely increased cancer incidence is far less than 1 per year (0.0004 estimated case per year).

## 1.14 What are the risks from LBNL tritium exposure to other LBNL workers and nearby facilities and residences?

An *individual* who works or resides in Zone 2 has a risk estimated to be six chances out of one million of incurring a cancer as a result of exposure to NTLF tritium (see Table 1-2). This risk is about 0.05 percent of the risk from background radiation of 11,000 chances in one million.

A conservative estimate of increased incidence of cancer for the *population* of 11,000 people who work or reside in Zone 2 is far less than 1 per year (0.001 estimated case per year).

## 1.15 Does LBNL tritium make it risky to live in Berkeley, or to wade or swim in Strawberry Creek or relax along its banks?

For Zone 3, the risk assessment considered two possible means of exposure to NTLF tritium: (1) Tritiated water carried by the wind to the population on or near the UC Berkeley campus and to Berkeley Hills residents living beyond Zone 2, and (2) tritiated rain water washed down Strawberry Creek. People could inhale tritiated water that evaporates into the air around Strawberry Creek, or absorb tritiated water when wading or swimming in the creek. Tritiated water is only present in the creek for short time periods, when rain washes tritium from the air around the NTLF into surface-water runoff that is carried down the creek. However, the risk assessment assumed that everyone in the exposed population wades or swims in the creek for two hours, 30 times per year, and that tritiated water is present on a year-round basis.

An *individual* who spends time in Zone 3 has an added risk estimated to be 0.9 chances out of one million to incur a cancer as a result of exposure to NTLF tritium (see Table 1-2). This risk is about 0.008 percent of the risk from background radiation of 11,000 chances in one million.

For an assumed *population* of 110,000 people in Zone 3, the increased cancer incidence is far less than 1 per year (0.001 estimated case per year).

# 1.16 Is it more likely that this study overstates or understates risk?

As indicated in Section 1.10, this risk assessment *assumes* that low-dose radiation does affect health. The health risk estimates here are extrapolated from effects observed only at high-dose levels. At lower dose exposures, health effects may occur at lower rates or may not occur at all. In the health physics community it has been observed that radiation damage from chronic low doses can be repaired naturally. Such chronic doses are believed to result in a smaller biological effect than is estimated from linear models that extrapolate from high-dose effects.

Every risk assessment makes assumptions in order to estimate future concentrations and exposures for the time periods over which risk is evaluated. For example, the emissions from the NTLF used to calculate tritium concentrations in all three zones is 100 **curies** (Ci) per year, which is slightly less than the average release from the NTLF since 1970 (138 Ci per year). The effects are discussed in Appendix D. In 1995 LBNL made permanent changes in NTLF operation, and the emissions in 1995 were 50 Ci [Thorson, 1996]. Future emissions are expected to stay at or below this level. Other assumptions of this study may result in an overestimate of risk, as follows:

- Individual risk for Zones 2 and 3 is calculated for residential exposure; i.e., an average exposure of 12 to 24 hours per day for 70 years.
- Estimated populations at risk (220 in Zone 1; 11,000 in Zone 2; 110,000 people on or near the UC Berkeley campus in Zone 3) are assumed to be in these areas every working day for 40 years for working populations, and every day of the year for 70 years for residential populations. It is likely that these numbers include people who are present in these zones for much less time.
- It is assumed that half of the population are women, that each of these women bears two children, and nurses each child for two years.
- Tritium content in garden produce in Zones 2 and 3 has been measured, and so far tritium is found below the detection level. However, because the uptake is theoretically possible, the risk assessment assumes that all 4,000 residents in Zone 2 and all 100,000 adults in Zone 3 eat tritium-contaminated garden produce on a regular basis, even though only a few of that population are residents with gardens.
- It is assumed that all 110,000 people of Zone 3 are in the $90^{o}$ sector with the highest estimated tritiated water concentrations in air.
- The risk assessment assumes that all 100,000 adults in Zone 3 wade in Strawberry Creek for two hours on a 30 days per year basis.
- The risk values are based on model estimates of tritium levels. Appendix F describes the dose based on urinalysis for workers over a four-month period

in 1995. These data were not available when this risk assessment was initially conducted. The estimated dose are greater than that from urinalysis.

These assumptions cause the risk assessment to overestimate risk. It should be noted that in the areas of highest potential exposure to NTLF tritium, LBNL does not rely on assumptions. NTLF staff exposure is measured each week and stack emissions are monitored continuously. LBNL has always maintained exposures well below the regulatory levels. Any increase of emissions will be detected immediately and corrective action will be taken to avoid increasing risk to workers and the public.

LBNL's environmental monitoring and oversight activities continue to assure that emissions from the NTLF stack and tritium levels detected in the environment stay below required levels. For example, in 1995, a tritium alarm was added that allowed off-hours monitoring by the LBNL Fire Department. Two significant engineering changes during 1995 included the addition of redundant valving on vacuum pumps close to the tritium source, and the replacement of the existing silica gel traps with broader traps which give the same flow, but have a higher HTO trapping efficiency. These and other engineering improvements have markedly diminished HTO releases from the NTLF, especially during the latter half of 1996. It is expected that the benefits of these changes will be realized in the future. Releases of tritium in 1996 have been at the same low rate measured in the last half of 1995.

## 1.17 Does LBNL tritium pose a significant risk to workers and the community?

To answer this question, let us first have a look at the comparison of people's estimated dose from NTLF tritium with those regulatory limits in Table 1-3

Table 1-3
Comparison of Estimated Does from NTLF with Regulatory Limits

| | Tritium Exposure Does (mSv/year) | | |
|---|---|---|---|
| | from NTLF | Federal & State Limits | ICRP Limits |
| Zone 1 | 0.024 [(a)] | 0.1 [(b)] | 1 [(c)] |
| Zone 2 Workers | 0.0013 | 0.1 [(b)] | 1 [(c)] |
| Zone 2 Residents | 0.0014 | 0.1 [(b)] | 1 [(c)] |
| Zone 3 | 0.0002 | 0.1 [(b)] | 1 [(c)] |

**Notes to Table 1-3:**
(a) The dose based on the 1995 urine analysis is about 10 times less than this estimated value.
(b) For inhalation only. (c) For all pathways

We may find that the exposures to tritium from the NTLF are generally several orders of magnitude lower than the regulatory limits. Using this table and the following comparison with risks due to background radiation, one may figure out how insignificant the added risk from NTLF is.

The estimated added lifetime cancer risk of 60 chances per million resulting from NTLF tritium for workers near the NTLF is very small—less than 1 percent of the risk of 11,000 chances per million resulting from background radiation. By contrast, background radiation in California can differ by as much as 30 percent from one region to another. The increased risks are much smaller—and no greater than 0.1 percent of background—for individuals who work elsewhere at LBNL, who live or work near the LBNL facility, or who use the UC Berkeley campus area.

There is no way to compare these risks directly with the value of the research conducted at the facility. This is an evaluation that the community and LBNL workers must make. The risk assessment conclusions suggest that the community and workers are supporting an important effort by accepting a relatively low level of added risk.

## 1.18 How reliable is this risk assessment?

To examine the validity and reliability of the results of this risk assessment, we have compared the exposure concentrations used in the risk assessment model (as input data) with available measured values. The ratios of input exposure concentrations to measured data are given in Table 1-4. Details of all numbers are given in Appendix F. In general, the used values are greater than the corresponding measured values. In other words, the input data are generally conservative in the direction of producing larger risk.

Table 1-4
Ratio of Input Data to Measured Data

| | Ratio of Input Data to Measured Data | | |
|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 |
| Air concentrations | 4.0 | 1.2 | — |
| Rain water | 5.5 | 6.5 | — |
| Surface water | 5.8 | 3.2 | 1.1 |
| Soil and sediments | 4.0 | 3.0 | — |
| Ground water | 2.1 | 4.8 | — |
| Vegetation (free water) | 0.84 | 1.1 | — |
| Body water levels | 9.8 | 1.4 | — |

The output (calculated risk) in Zone 2 of the model used for the risk assessment was also compared with that given by an independent EPA-approved model, CAP88-PC. The agreement between the two results is very good. Due to the inherent assumptions used in the CAP88-PC model, it is not appropriate for Zone 1 because of the proximity to the source and the complexity of the terrain, and Zone 3 because its non-realistic dose calculation for ingestion.

## 1.19 Organization of the rest of this report

Section 1A is a summary of how this version of the risk assessment was revised to address the comments received on the October 1995 draft version.

The remainder of this report consists of three chapters and nine appendices, followed by a glossary and references. Chapter 2 contains information about the nature of radiation and about the use of tritium at LBNL. Chapter 3 is an overview of the way in which the risk assessment was conducted. Chapter 4 is an in-depth discussion of the risk assessment calculations. Appendix A explains the compartment **model** used for much of the risk assessment to estimate the distribution of tritiated water in the environment. Appendix B explains how numbers were derived for use in exposure calculations. Appendix C gives the values used for environmental parameters. Appendix D explains how the effects of higher NTLF emissions from 1982 through 1989 were accounted for in the risk assessment. Appendix E provides a brief review of the EPA CAP88 computer model that was also used to assess tritium concentrations. Appendix E also lists computer-generated values from CAP88. Appendix F is a summary of how the input data used in the risk assessment compare to measured values of tritium found in the LBNL environment and by urine analysis from LBNL employees. These data were obtained in 1995 and were not available when this risk

assessment was drafted in 1994-95. Appendix G is a conversion table that gives US unit equivalents to the SI units used in this report. Appendix H contains comments from regulatory agencies on the draft of this risk assessment issued in October of 1995. Appendix I contains LBNL's 1993 fact sheet, "Questions and Answers About Tritium." Copies of the reviewers' letters regarding the final draft of the report are given in Appendix J.

# Chapter 1 Annex

# Response to Review Comments

The draft version of this risk assessment was reviewed by the California Department of Health Services; the U.S. Department of Health Services—Agency for Toxic Substances and Disease Registry; and the U.S. Environmental Protection Agency Region 9. Copies of their comments are contained in Appendix H of this report. Our responses to their comments are given in this Annex. Page references are to the draft version.

## 1A.1 Radiological Health Branch, California Department of Health Services

**Comment 1**

(1) The dose and risk estimates in Tables 1-2, 4-12, 4-13 and 4-14 are confusing and not demonstrated by Step-by-Step calculations in the report. Risk values in Table 1-2 do not match those in Table 4-12. References for cancer models should be footnoted with Tables. Cancer incidence estimates should be listed along with cancer mortality. The footnote on page 3-1 seems to be out of place.

*Response*

We have added Section 4.7.6, including a table (4-15) that gives step-by-step calculations. This section summarizes how the environmental concentrations convert to human exposure, dose, and risk. The table is cross-referenced to risk-assessment sections, equations and data used to make the transition from one stage of the calculation to the next.

Some risk values in Table 1-2 of the draft risk assessment were based on urine data and not on the model predictions used in Table 4-12. Since the model has been compared and reconciled with the urine data, we now use the somewhat higher risk levels predicted by the model in both tables.

Cancer incidence as well as risk levels are now included in the report. The footnote on page 3-1 has been removed.

**Comment 2**

(2) Comparison of annual exposures and associated risks to consensus standards is not consistent throughout the report.

*Response*

The report has been revised so that comparison to DOE regulations is provided consistently throughout the report.

**Comment 3**

(3) The atmospheric exposure pathway is only considered for Zones 1 and 2, but not Zone 3 west of Building 75. Since predominant winds are in the easterly direction airborne monitoring east of Building 75 would provide useful data for pathway analysis and dose assessment.

*Response*

We have added consideration of the air dispersion from NTLF to Zone 3 in Section 4.7.1.5 of the revised risk assessment.

In 1995 LBNL set up a network of eight sampling locations for collecting air samples for atmospheric tritium analysis, three onsite and five offsite. These locations are identified in Figure 4-1 of the 1995 LBNL Site Environmental Report [Thorson, 1996]. None of the current off-site sampling locations are due east of LBNL. However, rainwater is collected at six locations on site and analyzed for tritium. One of the rain water sampling locations is due east of the NTLF. Rain water sampling locations are identified in Figure 5-1 of the 1995 LBNL Site Environmental Report [Thorson, 1996]. Air and rain water sampling locations are selected to monitor those areas where predominant winds and residential and working populations coincide. The land east of LBNL belongs to the Regents of the University of California and is mostly open space. A discussion and analysis of the measurements obtained from the air and rain water tritium sampling network has been included in Appendix F of the revised risk assessment.

**Comment 4**

(4) It is not clear how the transfer of rain water and runoff to the upper watershed of Strawberry Creek is used in the risk assessment.

*Response*

To make this clear, we have added text to the beginning of Section 4.7.1.5, where this transfer is used to characterize tritium concentrations in Zone 3:

**Comment 5**

(5) Since the Agreement-in-Principle with DOE is terminated, the reference regarding Department of Health Services (DHS) oversight in section 1.16 should be clarified.

*Response*

Since the issue of oversight is not relevant to the risk assessment, and since the Agreement-in-Principle with DOE is terminated, we have elected to delete the paragraph describing the oversight role of DHS.

**Comment 6**

(6) No conclusion is made in Appendix D regarding the legacy of past elevated HTO emissions.

*Response*

We have revised Appendix D and added a conclusion section discussing the difference between the assumed release rate of 100 Ci/y and the average long-term release rate from the period 1970 to the present.

**Comment 7**

(7) It may be necessary to address the dose/response assessment to accidental releases.

*Response*

Section 3.3 has been added to Chapter 3 to address the issue of accidents.

### Comment 8

(8) There is no discussion or comparison of the results in Appendix F (Appendix E in final) and the results in Tables 1-2, 4-12, 4-13, and 4-14.

*Response*

We have added a section to Chapter 1 that compares the results in Appendix E (the old Appendix F) to the results in Zone 2, and discusses issues in the other two zones.

## 1A.2 Agency for Toxic Substances and Disease Registry

### Comment 1

(1) On page 1-8, 3rd paragraph, it would be prudent to describe what is meant by "high levels of radiation from HTO."

*Response*

In order to define what we mean by "high levels of radiation," we have added material to the paragraph in question.

### Comment 2

(2) On page 1-8, 4th paragraph, the conclusion that there is no experimental evidence in animals for HTO genetic effects is questionable. The reference on this issued should be checked and verified.

*Response*

The reference for this statement is "Tritium Risk Assessment," by T. Straume (1993). This paper is included in the list of references.

### Comment 3

(3) Section 1.10. Clarify the discussion on workplace exposure to distinguish internal and external doses.

*Response*

We have clarified the discussion here to indicate that all tritium exposures are internal exposures.

**Comment 4**

(4) Table 1-1, in preparing this table, the authors should review the United Nations UNSCEAR 1993 report for genetic effects and developmental effects that can be passed to successive generations (severe and heritable genetic effects).

*Response*

The UNSCEAR 1993 report uses the 1990 (ICRP-60) recommendations for heritable genetic effects and developmental effects. In these recommendations, the rate of heritable genetic effects within an exposed population is 0.013 per Sv. Using this factor, a calculated severe hereditary effect is added to the table.

**Comment 5**

(5) Page 4-5, the numbers here suggest a weighting factor [RBE] for tritium that is at the high end. Provide the public with some information here about what this means. Also, use microsieverts consistently throughout this paragraph instead of switching between sieverts and microsieverts.

*Response*

We have added a sentence to make clear the RBE that is implied here and have made sure that microsieverts are used consistently in this paragraph.

**Comment 6**

(6) Page 4-11, Section 4.5. Consider adding the pica (dirt-eating) child as an exposure scenario to this section.

*Response*

We did not and will not consider the dirt-eating child as an exposure scenario because, whatever one may take into consideration (air, soil, surface water or vegetation), what actually matters when it comes to tritium measurement is the equivalent water intake. The dirt-eating child may consume one gram (maybe even as much as 10 grams) of soil a day (long-term average). Soil contains about 10 to 20 percent water by mass; therefore, the total intake of water ingested amounts to less than one gram per day. The

amount of air inhaled by this child is 10 $m^3$ and contains about 100 grams of water. By considering inhalation, we have already taken credit for about 100 times the amount of tritium a child could possibly take in from soil.

**Comment 7**

(7) Section 4.5.1, the material on dermal uptake is confusing—what is the effective permeability of the system; does Ci/Ck incorporate the surface area available for absorption; where do equations 4-8 and 4-9 enter into equation 4-7?

*Response*

Sections 4.5.1 and 4.5.2 have been revised to make them less confusing.

**Comment 8**

(8) Page 4-19, second paragraph, update the discussion here to make clear that 10 CFR 20 limits annual worker exposure to 50 mSv from both internal and external sources and limits annual public exposure to 1 mSv from all exposure routes.

*Response*

We have updated the discussion to make this clear.

**Comment 9**

(9) Page 4-20, Section 4.6.4

Studies showing deleterious effects from tritium uptake were in the million Bq per liter range. These ranges may not be applicable to the concentrations around the LBNL tritium facility. You may want to consider this in the discussion of doses expected at the LBNL site.

*Response*

We have added a few sentences here discussing this issue.

### Comment 10

(10) Section 4.7.1.1, Is the source term release fairly uniform over a one-year period or are there short periods of time that account for the majority of the tritium release?

*Response*

The source term is rather uniform throughout the year. The weekly measurements in tritium emission have shown that: (1) there is release every week, and (2) the week-to-week variation of emission is within a factor of two of the average weekly release for about 60% of the time.

### Comment 11

(11) Section 4.7.2.1, is it appropriate to use the resting inhalation rates for average in inhalation rates?

*Response*

As the equation and discussion now make clear, we use an active or working breathing rate for 16 hours of the day and only use the resting breathing rate for an eight-hour period at night when people are assumed to be sleeping. These assumptions result in air intakes of over 20 $m^3$ per day, which have recently been shown to be conservative by almost a factor of two, since metabolically adjusted breathing rates are more typically in the range of 10 to 15 $m^3$ per day.

# 1A.3 US Environmental Protection Agency, Region IX Office in San Francisco

## Major Concerns

### Comment A

(A) Use cancer incidence and not fatal cancers as a measure of risk.

*Response*

We have revised the report to include both cancer incidence and fatal cancer.

### Comment B

(B) Use reasonable maximally exposed individual instead of an average individual.

*Response*

In the revised report we have altered the calculations to address the reasonable maximally exposed individual.

### Comment C

(C) Use concentric circles around the source instead of special partial circles.

*Response*

This change has been made in the revised report.

### Comment D

(D) Urine samples are used in place of the model to estimate risk in Zone 1, but the authors provide little detail on how the urine analysis was carried out and converted to dose and risk.

*Response*

We have revised the report so that model exposures are used consistently for all three zones. Urine analysis is used for comparison purposes only (see Table F-1). In Appendix F measured air levels are compared to predicted levels, measured soil and water levels are compared to predicted levels, and predicted tritium body burdens are compared to the urine analysis results for people in Zones 1 and 2.

## Minor Concerns

### Comment 1

(1) Why use world background radiation instead of background radiation for the Berkeley area?

*Response*

In the revised report, we compare our exposure estimates to background radiation in the Berkeley area.

**Comment 2**

(2) There is confusion about population dose and its significance. Authors should discuss the collective dose concept instead of multiplying the individual dose by 70 years and the population (i.e. in Table 1-1).

*Response*

To address this comment, we have added text to Section 1.12.

**Comment 3**

(3) The authors assume swimming in Strawberry Creek for one hour, fifteen days per year. This may be OK for an average, but is not for the maximally exposed individual.

*Response*

In the revised report, we assumed two hours of swimming at a time, 30 days per year.

**Comment 4**

(4) In Table 1-2, it is not clear how individual risk relates to population risk. This reviewer cannot determine the significance of individual risk. It is not for the maximally exposed individual.

*Response*

As is noted above, we have added text in Section 1.12 describing the difference between individual risk and population risk. In addition, we have added a summary table in Chapter 4 that provides a Step-by-Step review of the individual risk calculation. As is made clear below, our risk analysis as provided in the revised report does strive to estimate risk for the reasonable maximally exposed individual.

The first step of our analysis is to characterize the concentration of tritium in air, water, and soil of the proximate NTLF environment. The model reproduces the upper range of tritium concentrations that have been measured in the environment near the NTLF site. In air, tritium concentrations have been measured in the range of 10 to 100 $Bq/m^3$; in ground water and surface water runoff (hydraugers and streams) 40 to 800 Bq/L have been measured; and in rainwater 60 to 733 Bq/L have been observed [Schleimer and Pauer, 1991]. The reasonable upper bound tritium concentrations in each of the three exposure zones are estimated using the transport models described below. These concentrations are compared to recently measured values in Appendix F.

## Comment 5

(5) Is the model described in the report one developed at LBNL or is it a standard program that is not referenced.

*Response*

In order to address this comment we have added text to Section 4.7.1 of Chapter 4.

## Comment 6

(6) In Section 4.7.1 it is stated that average tritium concentrations are used in each zone. The highest reasonable concentrations should be used.

*Response*

Since we have revised the assessment to determine reasonable maximum doses, the first paragraph of 4.7.1 has been revised.